BBC RD 1976/4

1969 1974
THE QUEEN'S AWARD TO INDUSTRY

RESEARCH DEPARTMENT

REPORT

SOLID STATE IMAGE SENSORS: improvements in signal processing techniques

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THE BRITISH BROADCASTING CORPORATION

January 1976

BBC RD 1976/4
UDC 621.397.3:
621.397.611

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Summary

The work described in this Report is a continuation of that described in a previous Report No. BBC RD 1973/32 entitled 'Solid state sensors: the use of a single dimension 512 element array for film scanning'.[1] *This previous work resulted in the production of pictures from film using a 512 element switched-diode array. Whilst the pictures were of fairly good quality, they fell short of normal broadcast standards for two principle reasons; one was the insufficient resolution obtained and the other was the presence of fixed pattern noise appearing as vertical stripes in the picture background. This Report describes the techniques which have since been developed to combat these effects and gives an assessment of the picture quality now obtainable.*

Issued under the authority of

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

January 1976

(PH-152)

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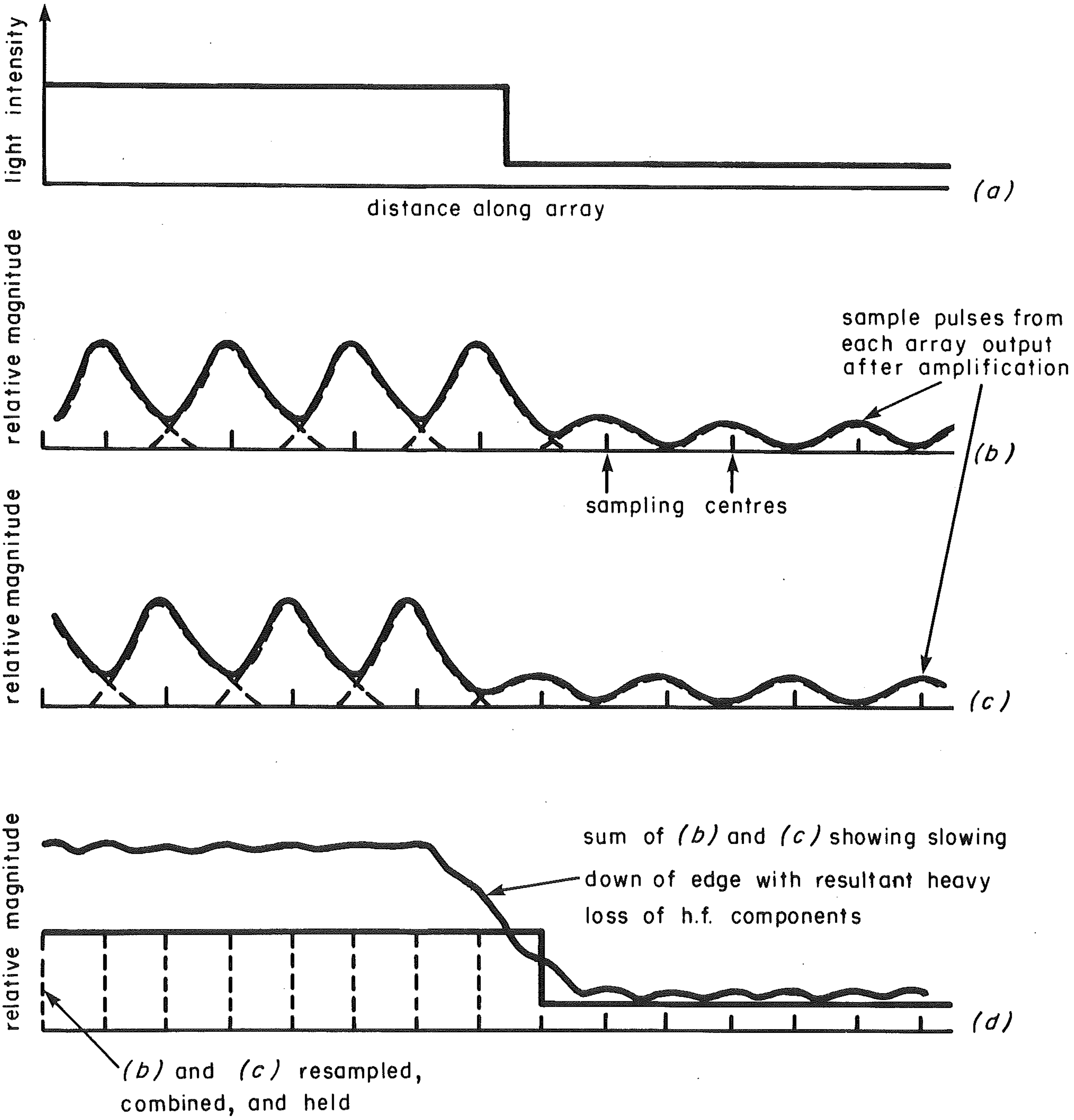
light intensity
distance along array
(a)
relative magnitude
sample pulses from each array output after amplification
(b)
sampling centres
relative magnitude
(c)
relative magnitude
sum of (b) and (c) showing slowing down of edge with resultant heavy loss of h.f. components
(d)
(b) and (c) resampled, combined, and held

Fig. 1

(*a*) Spatial variation of light into the array (*b*) Sampling pulses obtained from video 1 output after amplification
(*c*) Sampling pulses obtained from video 2 output after amplification (*d*) Two methods of combining the samples shown in (*b*) and (*c*)

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1. Introduction

This Report considers three different ways in which the performance of a linear solid state sensor array was improved by suitable signal processing. These fall under three headings:

(a) Re-sampling
(b) Aperture correction
(c) Fixed background pattern removal.

These separate improvements are to some extent interrelated; for example, it will later be seen that re-sampling provides some degree of aperture correction and also reduces the fixed background pattern. Nevertheless, it is convenient to consider them separately, pointing out any interdependence where it exists.

Most of the work described in this Report has been carried out using 16 mm film transported by a capstan-drive mechanism built in the Department. This mechanism was used to move an image of the film past the solid state sensor, the motion of the film thus providing the vertical scanning. Such an arrangement can only result in sequentially scanned images, since each film frame encounters the sensor only once. In future work it is intended to use a field store, to provide sequential to interlace conversion but, during the work described in this report, the film was run at 50 frames/sec instead of 25 frames/sec in order to produce interlaced signals that could be viewed on standard monitors and recorded. This capstan film drive equipment has permitted a much more critical assessment to be made of the array performance than hitherto, and has made it possible to demonstrate pictures of relatively high quality. Some of the work specifically concerned with the film transport mechanism will be dealt with elsewhere.

2. Re-sampling: general considerations

The 512-element diode array used consists of a single row of light sensitive diodes. Along each side of the diodes there is a 256-bit shift register, each stage of which drives an MOS switch which connects each diode in turn to a common busbar. The chip circuits are so arranged that there are two busbars to which the diodes are alternately connected and the clock pulses to the shift registers are so phased that signal pulses occur on each busbar output alternately. The busbar outputs, if fed into a low resistance load, produce pulses each of which decay with a time constant determined by the load resistance together with the busbar/diode capacitance.

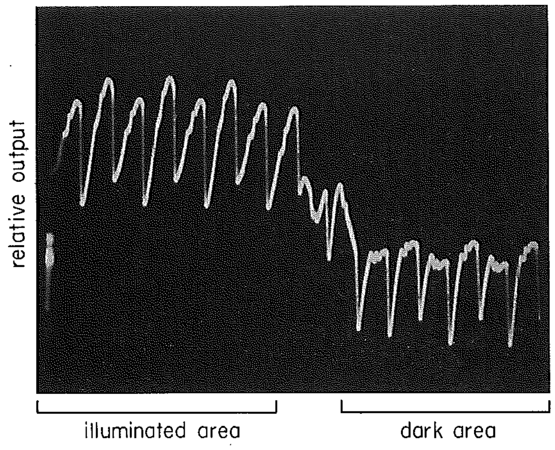

Fig. 2 - Output waveform obtained from one array output, after amplification

The manufacturer recommends that the two array outputs be connected together, thus combining the two sets of samples at a common output. This technique appears to be perfectly satisfactory when clocking the array slowly. At higher clocking rates, however, it becomes more and more difficult to prevent successive samples overlapping and this can cause a reduction in the horizontal resolution of the system. Experience has shown that this problem is greatly eased by processing the two outputs from the array separately, and only combining them together after this processing. Each array output is first amplified separately, and Fig. 1 shows the approximate shape of the sample pulses which might be expected, taking into account the time constant of the exponentially decaying pulses at the amplifier inputs together with the known amplitude response of the amplifier. This estimate of the sample pulse shape does not disagree with observations, although it must be pointed out that, as will be seen in Fig. 2, little can be deduced about sample pulse shape by observation of waveforms, because of the very large level of clock-pulse breakthrough always present on the array output. The sampling rate represented in Fig. 1 is 5 MHz for each array output. It can be seen that the samples on each output (shown dotted) overlap to some extent, but even so, they do not interfere significantly with each other at the sampling instants. Fig. 1(*d*) shows, however, that there would be considerable crosstalk if both sets of samples were combined together by simple addition. During the initial work on the array this arrangement was used, and the horizontal response/frequency characteristic barely extended up to 2·5 MHz. It was felt that improvement would result from re-sampling the pulses on each array output separately, thus producing two sets of clean samples which could be combined without crosstalk, also shown in Fig. 1(*d*). There would also be another advantage, namely that the spurious pulses on the output signal due to capacitive breakthrough from the clock drives would probably be reduced by re-sampling. These pulses are not shown on Fig. 1 for the

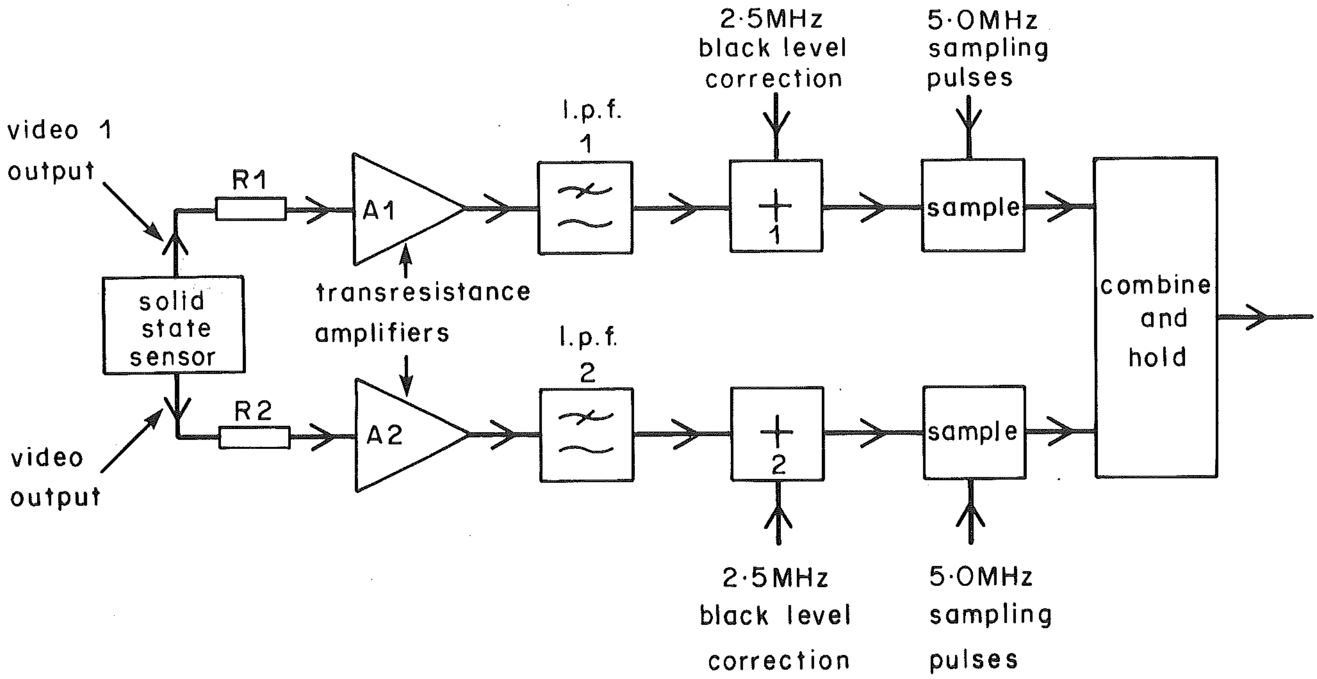

Fig. 3 - Block diagram showing signal processing of the array output

sake of clarity, but they are easily seen in the photograph, Fig. 2, which shows the shape of the waveform obtained at the output of one of the two pre-amplifiers. On the left-hand side, the array is illuminated, and on the right-hand side it is in darkness. The large negative pulses at 5 MHz are clearly seen in the 'dark' areas of the waveform. In the illuminated area, the waveform is formed from the sum of the 5 MHz output samples and the clock breakthrough. In addition to a strong 5 MHz clock breakthrough component a smaller component can also be seen with a frequency of 2·5 MHz, this 2·5 MHz component is an important source of picture impairment.

2.1. Block diagram

Fig. 3 shows, in block diagram form, the circuit arrangement used for the signal processing of the array outputs. The current pulses present in R1 and R2 from the array were converted into voltage variations in the transresistance amplifiers A1 and A2. The low-pass filters (1) and (2) were used to prevent any out-of-band frequency components from entering the sampling circuits; these might otherwise have given rise to aliasing. The choice of cut-off frequency for the filters had to be made with great care since it was known that this could have a profound effect on the mid-band response/frequency characteristic of the overall system. This will be discussed fully in Section 2.2. The adders were used to provide some compensation for the residual 2·5 MHz clock-pulse breakthrough component remaining after re-sampling. This operation will be described in Section 2.3.

2.2. The choice of cut-off frequency for the low-pass filter

Since, in this particular application, each of the two amplifier outputs consists of a 5 MHz sampled signal it would appear, according to sampling theory, that each low-pass filter can have a cut-off frequency of 2·5 MHz and still preserve all the useful information carried in each channel. This being so, it is instructive to consider how two channels, each restricted in bandwidth to 2·5 MHz can provide the information necessary to produce a signal having a 5 MHz bandwidth. Figs. 4(*a*) and (*b*) show the spectral components of two signals of 5 MHz bandwidth sampled at 5 MHz (for clarity the bandwidth is actually shown to be slightly less than 5 MHz). This is the signal which might be expected at the array outputs if the sampling pulses were sufficiently narrow. The more practical case, where the sampling pulses have the form illustrated in Fig. 1, will be dealt with later.

Sampling theory shows that the spectrum is repeated every 5 MHz. Those spectra centred at 5, 15, 25 etc. MHz are shown dotted, and separated from those centred at 0, 10, 20 etc. MHz for clarity. Those represented by dotted lines can be regarded as alias components due to having sampled a 5 MHz signal at 5 MHz, half the minimum Nyquist sampling frequency of 10 MHz. It should be noted that the dotted spectral components in Fig. 4(*b*) are drawn upside down. This is to illustrate the fact that they are in antiphase relative to their counterparts in Fig. 4(*a*); this is the spectral consequence of interlacing the sampling pulses between the two array outputs. As a cross check it can readily be seen that these alias components would cancel out if the two sets of samples were added together, a situation which would be equivalent to having sampled at 10 MHz in the first place. Figs. 4(*c*) and (*d*) show the signals filtered by 2·5 MHz low-pass filters. If (*c*) and (*d*) are then re-sampled with separate trains of very sharp 5 MHz sampling pulses which are interlaced one with the other, the spectra will be repeated every 5 MHz as shown in (*e*) and (*f*); however the repeated spectra centred at 5, 15, 25 etc. MHz will be in relative antiphase. If (*e*) and (*f*) are

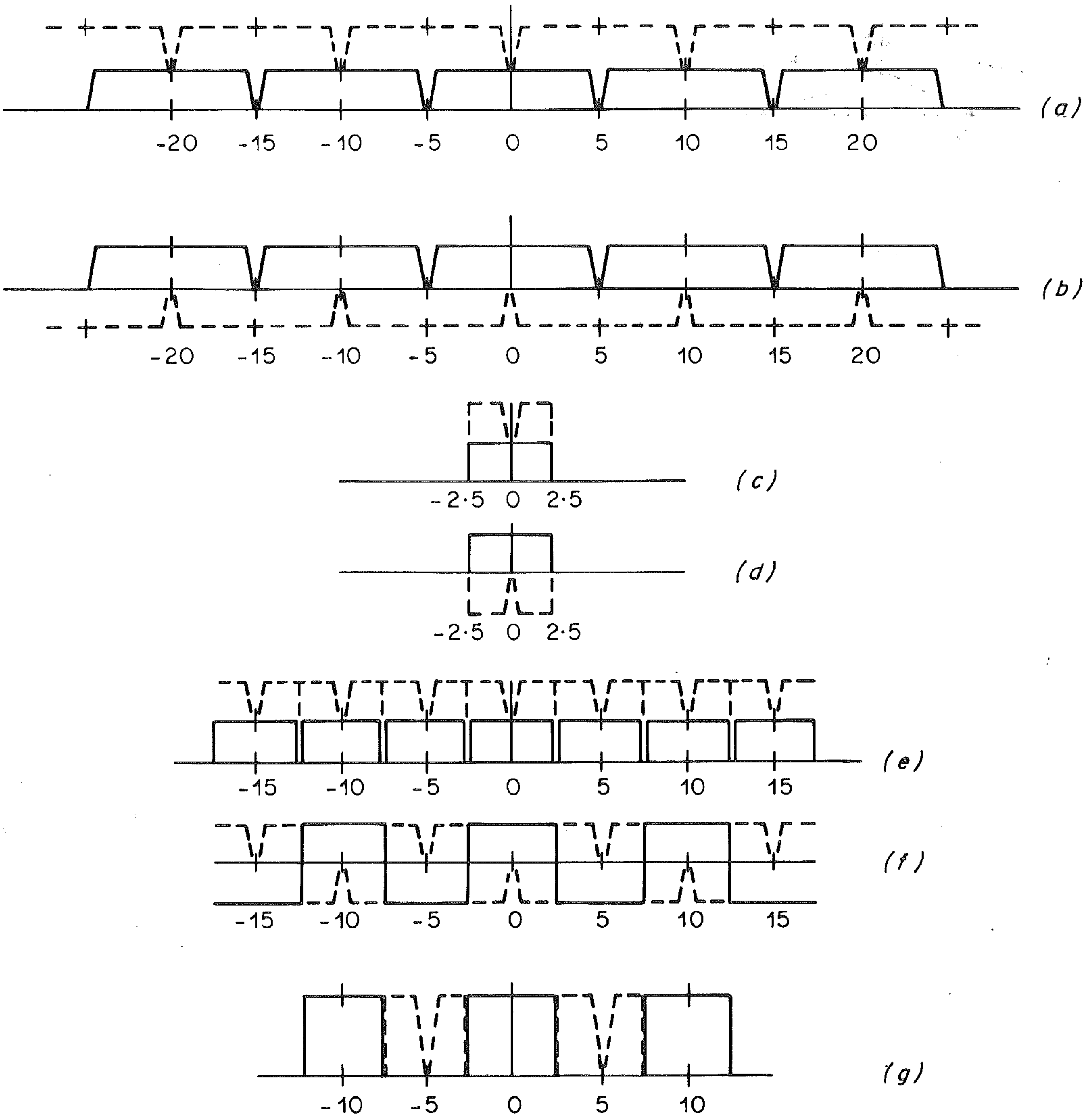

Fig. 4

(*a*) Idealised spectrum of video 1 output from the array (*b*) Idealised spectrum of video 2 output from the array
(*c*) Spectrum of video 1 passed through a 2·5 MHz L.p.f. (*d*) Spectrum of video 2 passed through a 2·5 MHz L.p.f.
(*e*) Spectrum of signal at (*c*) resampled (*f*) Spectrum of signal at (*d*) resampled with pulses interlaced with respect to those in (*e*)
(*g*) Spectrum of processing output, the sum of (*e*) and (*f*)

then added together, the resultant spectrum will be as shown in (*g*). It will be seen that the energy from 0 — 2·5 MHz is formed from the original baseband information, but the energy from 2·5 MHz to 5 MHz is formed from what were, in (*a*) and (*b*), alias components. Nevertheless these contain the correct signal information for this part of the band and all the signal information from 0 — 5 MHz can thus, in principle, be recovered in spite of the apparent removal of the 2·5 — 5 MHz part of the band by the low-pass filters.

In a practical situation, the samples from the array are far from being very sharp and have already been illustrated in Figs. 1(*b*) and (*c*). The effect of these imperfect sampling pulses is to cause a rapid falling off in the spectral response of the sampled signal. Figs. 5(*a*) and (*b*) approximately represent the spectra of these pulses; the response is considerably reduced at 10 MHz. The spectra after 2·5 MHz filtering and those obtained by re-sampling are illustrated in Figs. 5(*c*), (*d*), (*e*), (*f*) and (*g*); the description will

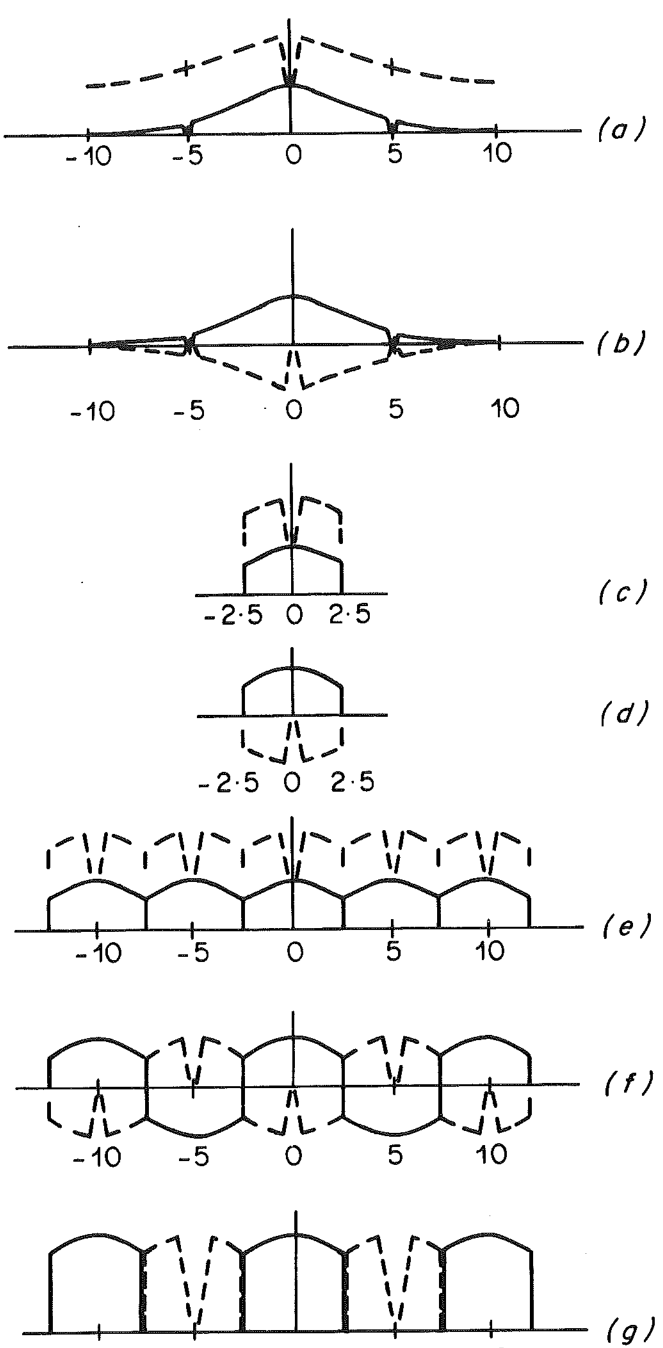

Fig. 5

(*a*) Realistic spectrum of video 1 output from the array
(*b*) Realistic spectrum of video 2 output from the array
(*c*) Spectrum of video 1 passed through a 2·5 MHz L.p.f.
(*d*) Spectrum of video 2 passed through a 2·5 MHz L.p.f.
(*e*) Spectrum of signal at (*c*) resampled
(*f*) Spectrum of signal at (*d*), resampled with pulses interlaced with respect to those in (*e*)
(*g*) Spectrum of processing output, the sum of (*e*) and (*f*)

not be repeated as it follows the same sequence as in Fig. 4. Fig. 5(*g*) shows the final spectrum which illustrates that the alias component provides some compensation for the falling response at high frequencies, but the response drops in mid-band, and has a discontinuity at 2·5 MHz.

The experimental results using 2·5 MHz low-pass filters confirmed that information between 2·5 MHz and 5 MHz could indeed be recovered in this way, but the overall response was unsatisfactory largely because it appeared impossible to achieve a smooth transition from the baseband part of the spectrum, 0 – 2·5 MHz to the 'alias' part of the spectrum, 2·5 – 5 MHz. The response at around 2·5 MHz clearly relies rather heavily on the response/frequency and group-delay/frequency characteristics of the 2·5 MHz filters at around their cut-off frequencies, and a satisfactory performance in this respect could not be easily achieved.* The use of 5 MHz low-pass filters was therefore considered. The same sequence of arguments can be used to illustrate the effect of using 5 MHz low-pass filters in place of the 2·5 MHz filters, and the process is illustrated in Fig. 6. Fig. 6(*g*) shows how the resultant signal is formed from a baseband signal and an overlapping alias component. As before, however, the 'alias' component contributes to, rather than interferes with the output, and it also provides some compensation for the poor h.f. response of the baseband signal, but without introducing a discontinuity in mid-band. This has proved satisfactory, and has led to the choice of 5 MHz as the cut-off frequency for the low-pass filters shown in Fig. 3.

2.3. The coarse cancellation of 2·5 MHz clock breakthrough

In order to operate, each shift register in the array which operates at 5 MHz, requires two phases of clock pulse, each at 2·5 MHz; thus the entire array requires four different phases of clock pulses at 2·5 MHz. A certain proportion of the clock-drive signal appears at each output of the array due to capacitive breakthrough from one or more of the four clock-pulse trains within the device; this causes interference which is particularly troublesome since 2·5 MHz is in the middle of the video band. It is therefore of paramount importance to try and remove this source of interference. Much of it may be removed by careful attention to the layout of the clock-drive circuits and most of that which remains may be removed by adding a 2·5 MHz correction signal before re-sampling. This is illustrated in Fig. 7. Fig. 7(*a*) shows a typical signal which can appear on either of the two 5 MHz filter outputs (see Fig. 3) when the array is uniformly illuminated. A periodic variation between the magnitudes of alternate sampling peaks is typical of the signal at this point and is caused by the added component at 2·5 MHz. It should be noted that, although in the example given the 2·5 MHz component is drawn in phase with the 5 MHz sampling, this is not necessarily so in general, and the effect on the magnitudes of the sampling centres will be a function of this phase relationship. If, for example, the zero crossings of the 2·5 MHz component were to lie on the sampling centres, the 2·5 MHz component would have no effect on the re-sampled signal. The example in Fig. 7 therefore shows the most damaging phase

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* Since the drafting of this report, further work using a solid state sensor of a different type has suggested that it may be possible to achieve the required matching between the amplitude and group-delay response/frequency characteristics of the filters at around cut-off frequency, using various transversal filter designs.

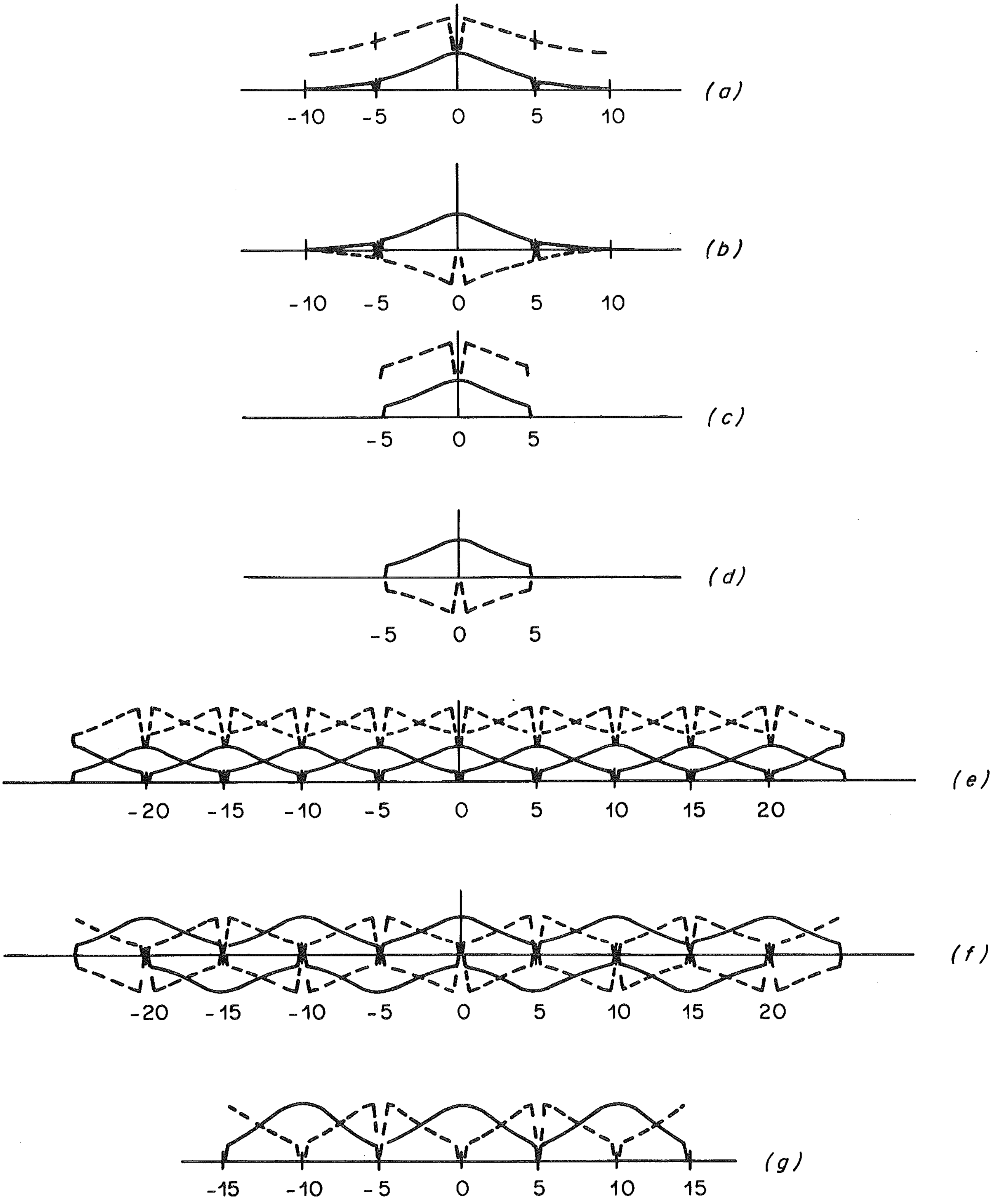


Fig. 6

(*a*) Realistic spectrum of video 1 output from array (*b*) Realistic spectrum of video 2 output from array
(*c*) Spectrum of video 1 passed through a 5 MHz L.p.f. (*d*) Spectrum of video 2 passed through a 5 MHz L.p.f.
(*e*) Spectrum of signal at (*c*) resampled (*f*) Spectrum of signal at (*d*) resampled with pulses interlaced with respect to those in (*e*)
(*g*) Spectrum of processing output, the sum of (*e*) and (*f*)

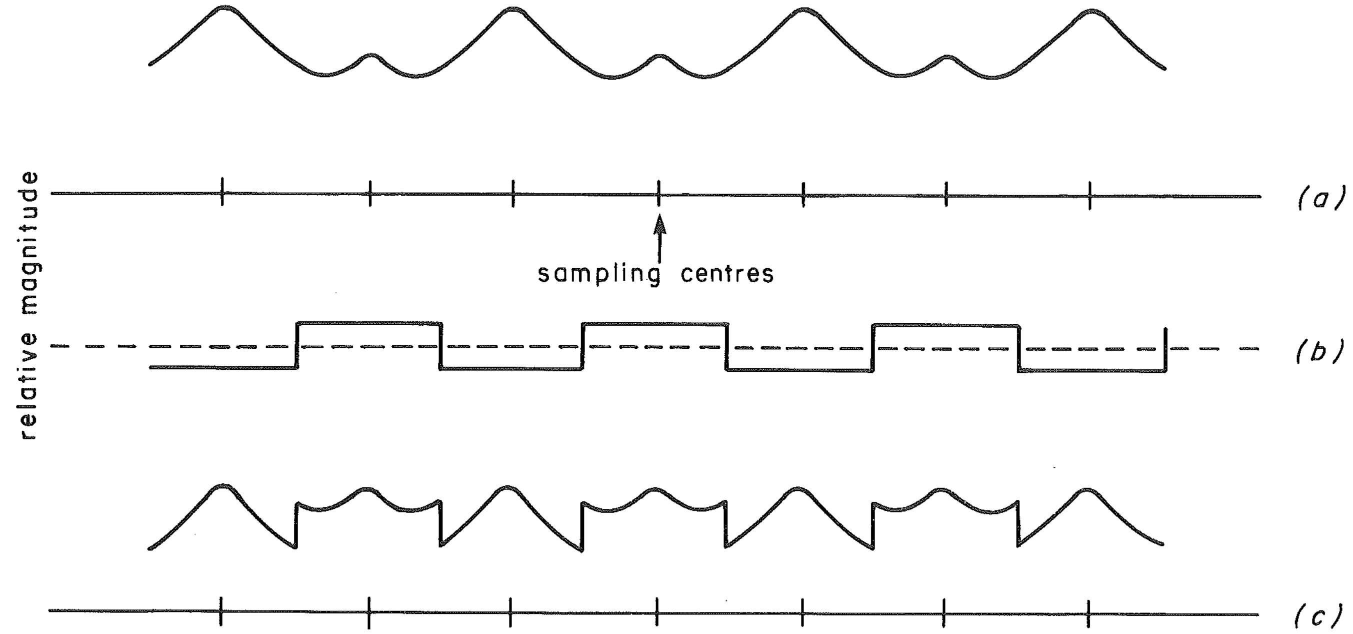


Fig. 7 - The removal of 2·5 MHz components by cancellation
(*a*) Typical video 1 or video 2 output with 2·5 MHz clock breakthrough (*b*) 2·5 MHz square wave of appropriate amplitude
(*c*) Sum of (*a*) and (*b*) showing sampling centres at equal heights

relationship that can exist. It should further be noted that, at the array output this 2·5 MHz component consists of periodic impulses; it is only after the 5 MHz filters that it appears substantially sinusoidal. Fig. 7(*b*) shows a 2·5 MHz square wave, the amplitude of which can be adjusted. If this is added to the waveform of Fig. 7(*a*) the resultant waveform is that shown in Fig. 7(*c*). Although this waveform is discontinuous, due to the addition of the square wave, the samples are now taken at the same level and, when the signal is re-sampled, it will be free of 2·5 MHz components.

In practice this system worked satisfactorily, but there were residual added components at a low level (approximately ±0·25%) which could not be removed in this way. It was also found that cancellation was not entirely uniform along the array, due to masking tolerances in the manufacture of the device, and there was some evidence of low-level random dark-current variations. In spite of the low level of these effects they were visible in the dark areas of a picture. Further processing was therefore desirable in order to reduce this interference to an acceptable level; this will be described in Section 4.

3. Aperture correction

3.1. Horizontal aperture correction

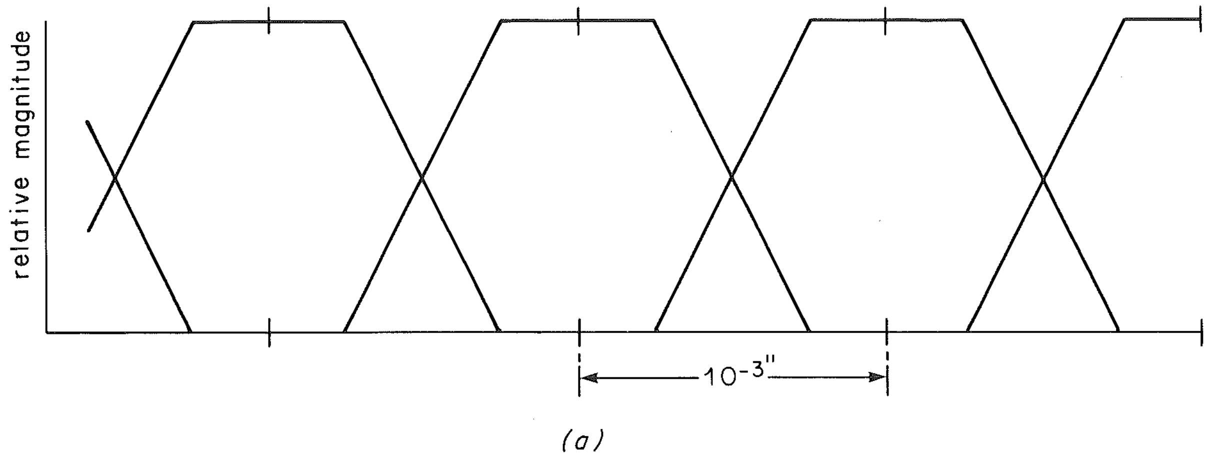
Horizontal aperture correction is necessary to compensate for aperture losses in the film, the optics, the sensor and the sampling process. No accurate prediction can normally be made as to the total horizontal aperture correction necessary, because some parameters are normally unknown.

The effective horizontal aperture shape for the photodiodes, as published by the manufacturer, is shown in Fig. 8(*a*). This is an 'idealised' shape rather than one that has been measured but, apart from a general rounding off of the edges, there is no reason to suppose that the actual response does not approximate to this reasonably well. Fig. 8(*b*) shows the corresponding calculated spectral response in relation to the sampling frequency f_H ; the 'ideal' rectangular response cutting off at the Nyquist limit (half sampling frequency) is also shown. At the Nyquist limit the calculated response is −4·8 dB and this indicates the amount of frequency correction needed to compensate for the array aperture.

In the re-sampling process, a sample and hold technique is used, i.e. the value of each sample in the output waveform is held until the subsequent one. This provides a form of filtering which falls short of the ideal but is instrumentally convenient and commonly used; such processing causes a loss of 3·9 dB at the Nyquist limit. This together with the effect of the array spectrum makes a combined loss of 8·7 dB at 5 MHz. It can therefore be seen that a significant amount of aperture correction is needed to achieve a flat overall characteristic, although it should be noted that in practice, optimum subjective image sharpness does not necessarily imply a uniform response.

3.2. Vertical aperture correction

In the film-scanning experiments the image horizontal size was 0·512 ins. (1·30 cm) as defined by the array dimensions. Thus, the vertical image size was ¾ x 0·512 ins. = 0·384 ins. (0·975 cm). Since 575 active lines are scanned, it follows that the spacing between lines was 0·384/575 = 0·668 x 10^{-3} ins. (1·697 x 10^{-3} cm). The



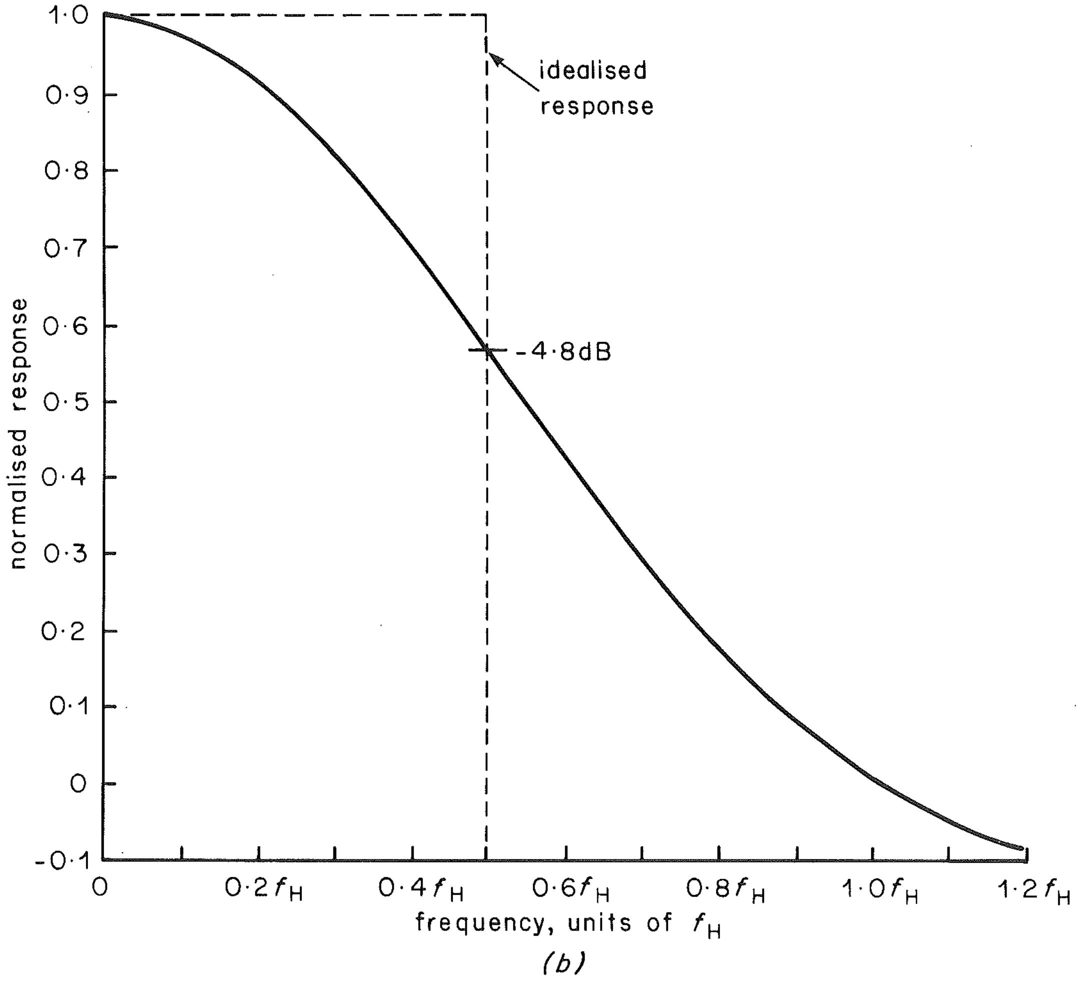


Fig. 8
(*a*) Manufacturers published horizontal aperture (*b*) Equivalent spectral response

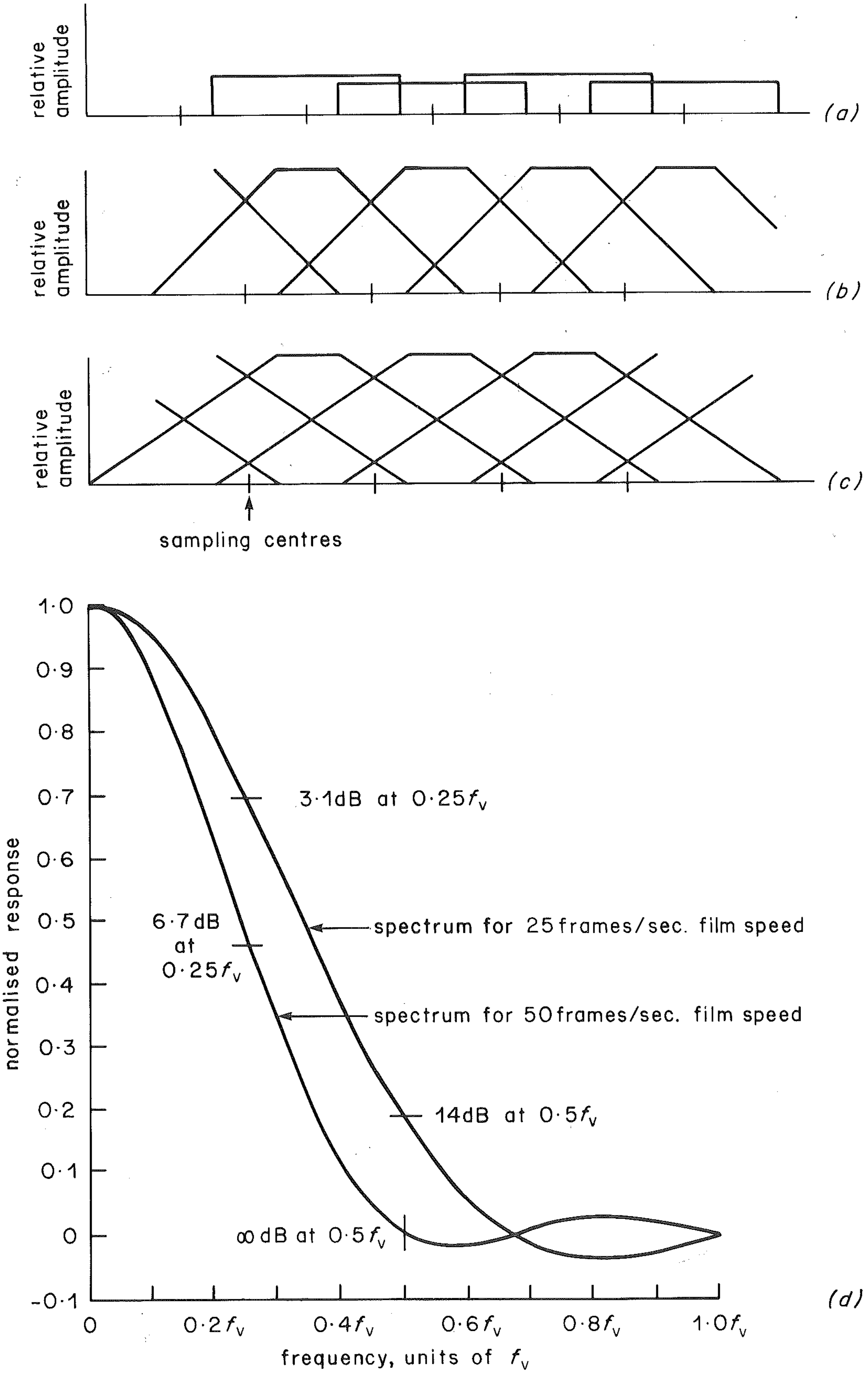


Fig. 9

(*a*) Vertical aperture of the array when film is stationary (*b*) Vertical aperture of the array when the film is running at 25 frames/second
(*c*) Vertical aperture of the array when the film is running at 50 frames/second
(*d*) Vertical spectra obtained with 25 and 50 frames/second film speed respectively

vertical aperture, as defined by the aluminium mask on the array, was 10^{-3} ins. ($2{\cdot}54 \times 10^{-3}$ cm) wide; this is more usefully expressed as 1/0·668 = 1·5 vertical scanning intervals. Fig. 9(*a*) shows the resultant array aperture in relation to the vertical sampling pulses, this would be the vertical aperture if the film were stationary.

In the experiment, the film moves and the array integrates the light over a strip of moving image corresponding to one line period, thus considerably modifying the effective vertical aperture to an extent which depends on the film speed. For example, if the film moves with its correct speed of 25 frames/sec so as to produce a sequentially scanned television signal, the aperture will be as shown in Fig. 9(*b*). If, however, the film is run at twice its normal speed in order to produce interlaced scanned pictures directly, the effective vertical aperture will be modified to that shown in Fig. 9(*c*). The corresponding spectra are plotted in Fig. 9(*d*), and the drop in response at $0{\cdot}25f_v$ and $0{\cdot}5f_v$ is indicated, where f_v is the vertical sampling frequency in lines/picture height.

Not surprisingly, the spectrum corresponding to the lower film speed has greater high vertical-frequency content and therefore requires less vertical aperture correction in order to achieve a satisfactory subjective result.

The fact that the images are sequentially scanned for 25 Hz operation means that vertical aperture correction is capable of peaking at $0{\cdot}5f_v$ rather than at $0{\cdot}25f_v$, as with interlaced signals. It remains to be seen whether any undesirable 25 Hz interfield flicker effects will appear when this is done. Since the work described in this Report was carried out using the 50 frames/sec film speed, more vertical aperture correction was needed, and the results, although subjectively pleasing cannot be taken to represent the performance of the array in its finally intended mode of operation.

3.3. Resolution realisable with aperture correction

Fig. 10 shows a photograph of test card C reproduced running at 50 frames/sec, for film using the 512 element sensor, and with horizontal and vertical aperture correction subjectively judged to be optimum. A notch filter was present in the system at 5 MHz to remove any clock breakthrough at this frequency. The response is broadly uniform to about 4 MHz and falls by a few dBs at 4·5 MHz. Clearly these results are close to the best that can be expected with a 512 element array. It should be explained that the apparent response at 5·5 MHz is due to an alias component, caused by a beat between the 5·5 MHz bars and the 10 MHz sampling rate, with a frequency of 4·5 MHz. This, as expected, illustrates clearly that 512 is not a sufficient number of elements for a 625-line system having a nominal 5·5 MHz bandwidth.

The vertical response appears to be subjectively satisfactory but, as has been pointed out, this is not representative of the performance potentially available with a 25 frames/second film velocity.

4. The removal of background striations by storage techniques

4.1. Description of the technique

It has already been indicated that the picture provided by the signals emerging from the signal processing circuit shown in Fig. 3, although comparatively free of impairments, is impaired by a residual background pattern of vertical striations due to a number of causes of which incomplete cancellation of clock breakthrough is an important one. The subjective impairment so caused may be gauged from Fig. 11, where attention is drawn to the road surface in the lower half of the picture. In this dark area of the picture vertical striations can clearly be seen. These are due to a combination of incomplete cancellation of clock breakthrough, together with a more random component thought to be due to dark current variations within the array. These components are added to the picture signal and are always present, but are mostly visible in the dark areas of the picture.

Another type of impairment, also resulting in vertical striations, appears in the well illuminated parts of the picture and, in Fig. 10, may just be seen in the white areas. This form of impairment is signal level dependent and to a good approximation may be regarded as a linear modulation of the picture components. This is partly caused by sensitivity variations between photo-diodes and partly due to a component of the clock breakthrough which modulates the signal output within the array.

The combined effects of these impairments may be represented by the expression

$$E_0(t) = \alpha(t) + \beta(t)E(t)$$

where $E_0(t)$ = uncorrected output from the array, a function of time (t)

$\alpha(t)$ = fixed pattern noise added to the output

$\beta(t)$ = fixed pattern noise modulating the output (sensitivity variations etc.)

$E(t)$ = desired signal, without impairment.

A technique was developed to remove the interfering components $\alpha(t)$ and $\beta(t)$ which depended on following a setting up procedure in which correction signals could be obtained from the array itself and stored for future use.

Fig. 12 illustrates how the process can, conceptually, be carried out. The technique involves the following stages.

(1) Light is excluded from the array, hence $E(t) = 0$, and $\alpha(t)$ appears at S1. S1 is closed for one line-period, thus storing $\alpha(t)$ in line store 1. $\alpha(t)$ is thereafter available for subtraction from the main signal in subtractor 1. This leaves $\beta(t)E(t)$, the logarithm of which is now taken.

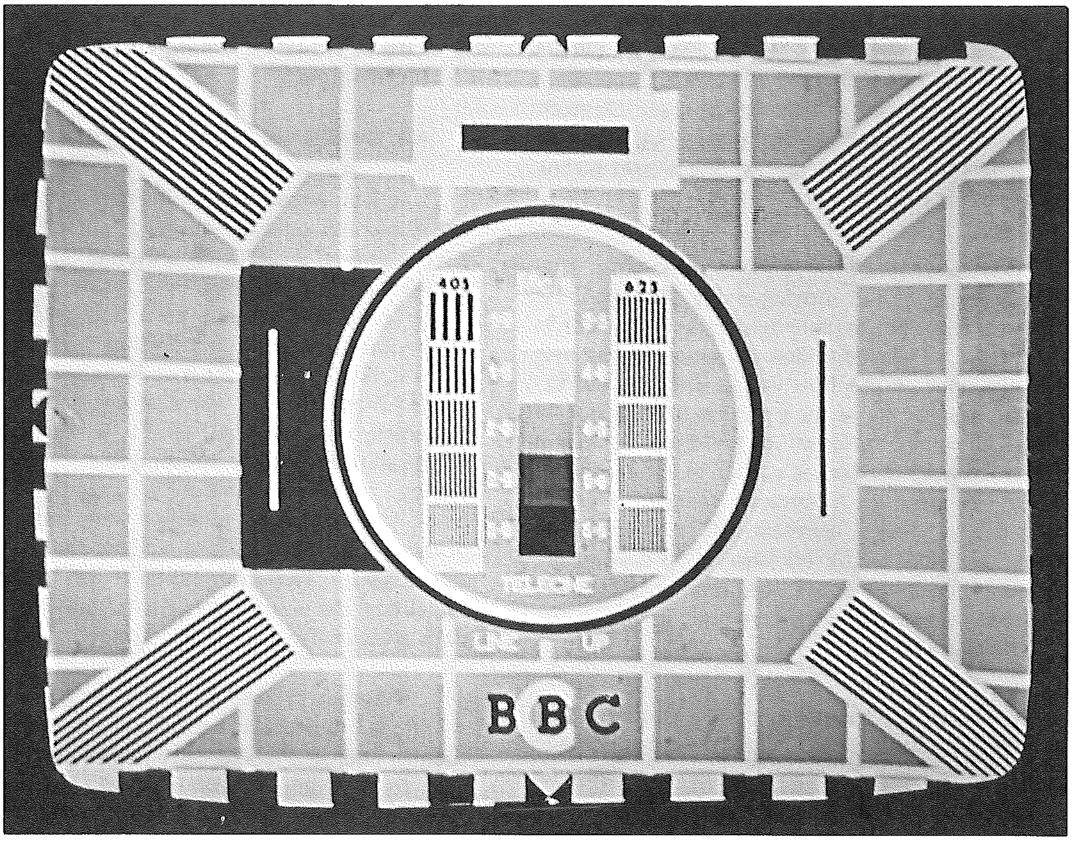


Fig. 10 - Test Card C showing resolution obtainable

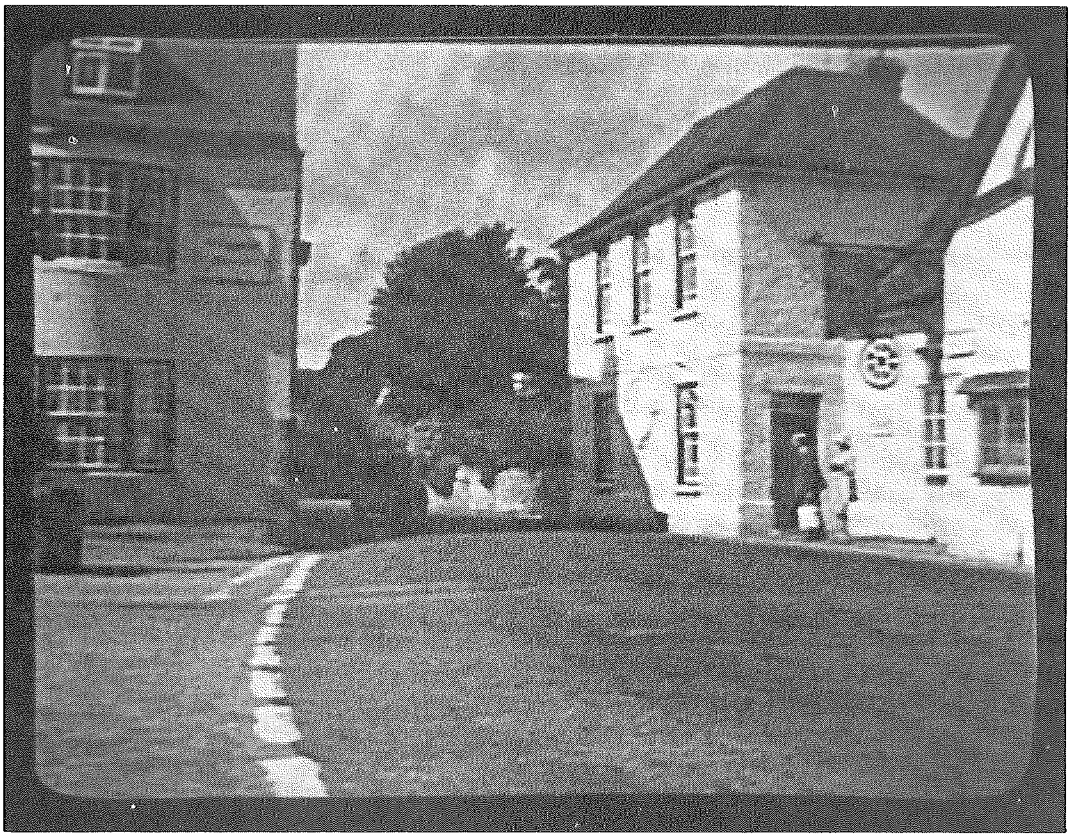


Fig. 11 - Scene chosen to illustrate the visibility of vertical striations

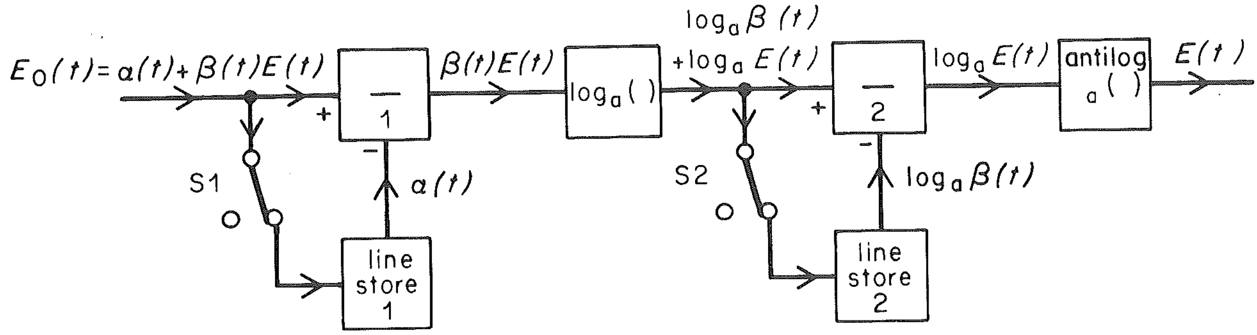


Fig. 12 - The removal of vertical striations by storage: conceptual system

(2) In the second stage of setting up, the array is uniformly illuminated to full intensity. The signal produced under these conditions is, by definition, $E(t) = 1$ hence the signal at S2 will be $\log_a\beta(t) + \log_a(1) = \log_a\beta(t)$. This is stored in line delay 2 by closing S2 for one line-period. Thereafter, $\log_a\beta(t)$ is subtracted from the main signal in subtractor 2, leaving $\log_a E(t)$. The antilog converter then gives $E(t)$, the desired signal, free of interference.

It will be clear that the entire process can, in principle, be carried out digitally, and this is indeed the only fully satisfactory method of storing the signals in the line stores. The use of digital techniques for the signal processing inherently has limitations, however.

At present, ADC's operating at video frequencies are limited to eight-bit accuracy. This has been found to give satisfactory level quantisation for the coding of gamma-corrected signals, but it is not very satisfactory if used to code unity-gamma signals such as those generated by the solid-state sensor. For this purpose it is thought that up to 12 bits may be required,[3] or, alternatively, that a logarithmic ADC should be used. The normal effect of insufficiently fine quantisation is to cause obvious quantisation noise (e.g. contouring) in the dark areas of a picture. For example, with eight bit coding, and a gamma corrector with an exponent of 0·5, the first step from black to 1/256 of white level becomes 1/16 of white level after correction. Until ADC's of improved level resolution become available it is possible to mitigate this effect by introducing appropriate levels of noise and dither; however, somewhat noisy pictures result. These limitations in the ADC can have more serious consequences when trying to remove the component of the vertical striations represented by $\alpha(t)$ in the preceding expression. $\alpha(t)$ is typically of the order of magnitude of the smallest quantum level of an eight bit system (1/256). This can clearly result in considerable quantising errors in the signal stored in line store 1, and these quantising errors will be made obvious by vertical coherence; indeed, the picture may appear worse with the correction applied.

It is therefore necessary to store the background correction signal at an artificially high level. This is done by increasing the signal level into the ADC during the period in which the switch S1 is storing the background correction signal in line store 1. In this way the levels of the quanta are made small in comparison with the level of the stored signal. It is, however, necessary to attenuate the output of line delay 1 before subtraction from the main signal. In order to avoid further quantising errors this is best performed in the analogue part of the signal path before the signal enters the ADC. This is illustrated in Fig. 13. The switches S0, S1 and S2 are shown in the positions appropriate for storage of the correction signals.

The system illustrated in Fig. 13 was built and appraised. It proved possible to correct large errors of the types represented by $\alpha(t)$ and $\beta(t)$, but the smaller errors, particularly those of the $\alpha(t)$ form could not be removed because of errors in the stored correction signal caused by added, 'frozen' random noise introduced during the storage of the correction signals.

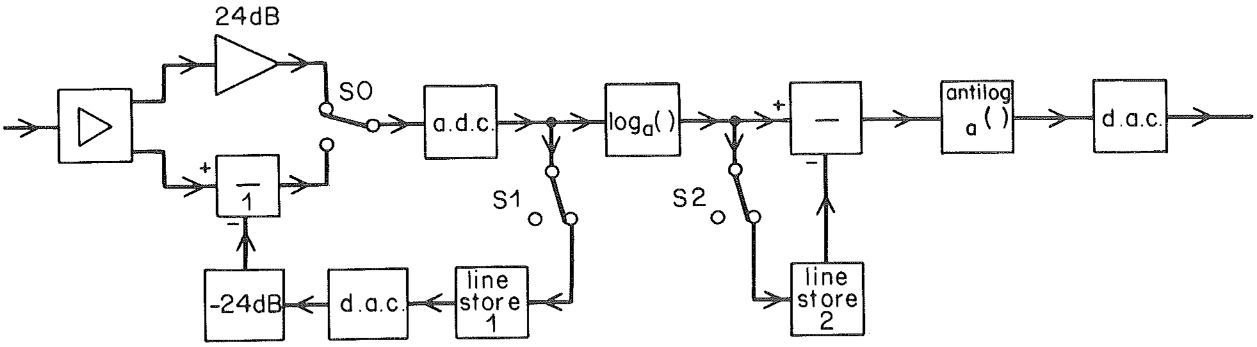


Fig. 13 - The removal of vertical striations by storage: practical block diagram

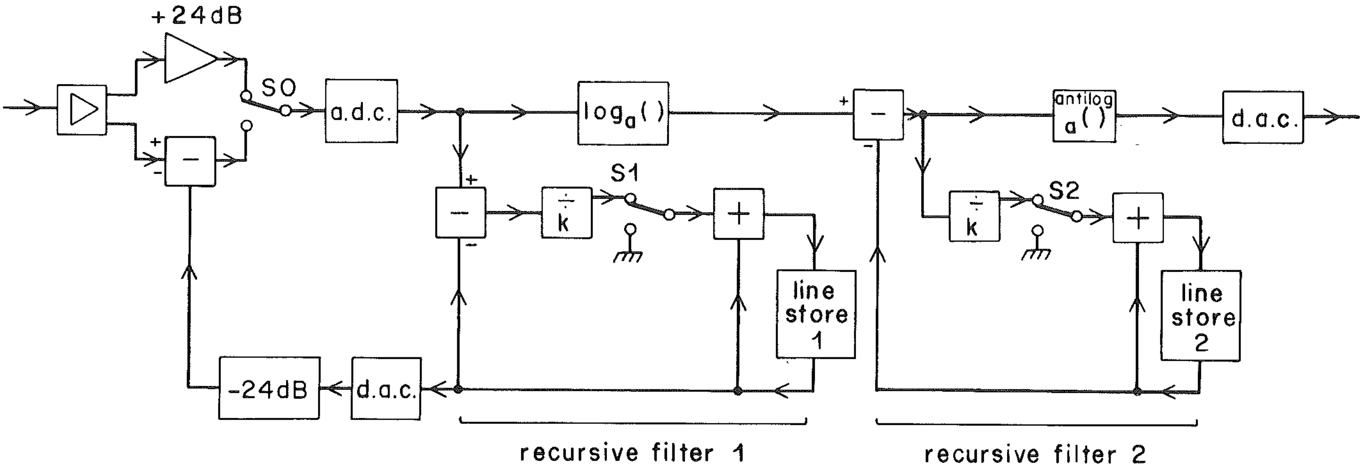


Fig. 14 - Block diagram showing proposed improvements involving recursive filters

The effectiveness of the system shown in Fig. 13 was thus shown to be limited by random noise level, and the noise level encountered was in practice too high.

4.2. Future work

Further work is anticipated in this area, since the ability successfully to cancel background blemishes is very important to the future prospects for solid state image sensor applications in broadcasting generally. A more promising approach to the problem is illustrated in Fig. 14. It will be seen that this is basically the same system as illustrated in Fig. 13, but with the addition of two first order recursive filters. Consider for example recursive filter (1). With the switch S1 in the position shown (the recursing mode) information that is repeated during every line, i.e. $\alpha(t)$ gradually accumulates in the line store over many lines whilst information that is different on every line will be attenuated (i.e. random noise). The degree of improvement in signal to noise ratio will depend on the choice of a value of K, and would for example be 18 dB for K = 32.

Having generated a virtually noiseless correction signal in the recursive filter, switch S1 is thrown to the 'earthed' position, and under these conditions the line delay recirculates $\alpha(t)$ while it is required. $\beta(t)$ can similarly be extracted from noise and stored.

5. Conclusions

This work has led to a greater understanding of the nature and properties of signals produced by solid state image sensors, and has resulted in the development of improved techniques for processing the signal in order to minimise the shortcomings of the array itself. Whilst the device used in this work is not fully representative of solid state sensors as a whole, many of the principles and techniques are likely to be applicable in future work with other devices (e.g. CCD sensors).

Figs. 10 and 11 are fairly representative of the picture quality achievable and this has been judged to be not very far short of broadcast quality.

The removal of spurious striations and blemishes from the picture remains the greatest signal processing problem so far; whilst sufficient success has been achieved to establish that the method described is feasible, further work will be required to offset the effects of noise in the stored correction signals.

Future work is planned with a CCD area array to complement the work already carried out with a linear diode array. In particular it is planned to examine the nature of striations and blemishes found on present day area arrays. These blemishes usually appear as white dots randomly distributed over the picture and it is thought that they may represent signal disturbances that, in some cases, are too large to be dealt with by the techniques described. It may, for example, prove necessary to reject the signals from such blemishes completely and to mask the effect of this by substituting interpolated estimates of the picture information. The knowledge gained from this work will assist in drawing up a specification for solid state arrays likely to be acceptable for broadcast applications.

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Printed by BBC RESEARCH DEPARTMENT, Kingswood Warren, Tadworth, Surrey, KT20 6NP